spotlights

Positive Vibes

Now hear this: Sound waves allow researchers to see deep inside objects too difficult or dangerous to cut into for a direct look. The Laboratory's Dipen Sinha has made a career of it, pioneering one successful application after another, and is now working toward his crowning achievement to date, using sound waves to treat—not just diagnose, but treat—just about every manner of debilitating brain condition commonly known.

What began during the first Gulf War with acoustic techniques to scan for chemical weapons inside unexploded munitions has since evolved into a series of imaginative solutions to other vexing peer-inside problems. Sinha developed acoustic methods for assessing how much water, oil, or natural gas is produced from any oil well. He subsequently aimed sound beams at eggs to identify those carrying salmonella. He worked out a way to test for glaucoma by measuring vibrations caused by collimated sound waves impinging imperceptibly on the eye. He upgraded biological laboratory research by adding acoustic capabilities to flow cytometers—machines that separate cells of different types from a mixed tissue sample. Then he turned his attention to the human brain.

Initially, Sinha showed that he could measure intracranial pressure (ICP)—the fluid pressure in the brain—using sound transducers placed against the subject's temples to produce and measure microscopic, ICP-dependent vibrations from the skull. Elevated ICP is often the key piece of information needed to properly diagnose life-threatening, combat-related and other head-trauma injuries, but the current method of monitoring it requires an enormously risky procedure. Doctors must drill into the skull and insert a catheter deep into the brain's interior, exposing the patient to a serious risk of potentially fatal infection. Yet Sinha's acoustic vibrations, imperceptible to the patient, provide ICP monitoring with none of the risk. They even reveal subtle changes in the ICP caused by, for example, a simple tilting of the head—such as when a driver begins to nod off at the wheel.

But sound waves are good for more than just noninvasive measurements in the brain. They can actually stimulate neurons with acoustically driven pressure waves, causing them to fire in much the same way as electrode-delivered impulses do. And that opens the door to a whole slew of potential medical advances.

"We in the field can already trigger neurons in a petri dish with sound," says Sinha. "And we already have good evidence that equivalent electrical stimulation can relieve a number of serious disorders—including Parkinson's disease, chronic pain, and deep depression—and even increase creativity. It's not such a big leap to expect the same treatment to work with sound beams, without all the complications associated with inserting electrodes into the brain."

Sinha refers to a neurosurgical technique known as deep-brain stimulation (DBS), which is just what it sounds like. In practice, electrodes placed deep in the brain are connected to wires leading to the cranial equivalent of a pacemaker. The device generates controllable electrical signals designed either to disrupt overactive brain circuits or stimulate underactive ones, wherever they may reside. For the tremors of Parkinson's disease, the electrodes are placed in the thalamus; for depression, in the mood center of the brain known as Area 25; for Alzheimer's disease, in regions associated with memory, cognition, or neurotransmitter activity. (DBS treatment is currently approved for Parkinson's and other movement disorders as well as obsessive-compulsive disorder; it is currently under study for depression, Alzheimer's, and chronic pain.) Not surprisingly, the success of DBS relies on properly positioning electrodes within the problem area of the brain.

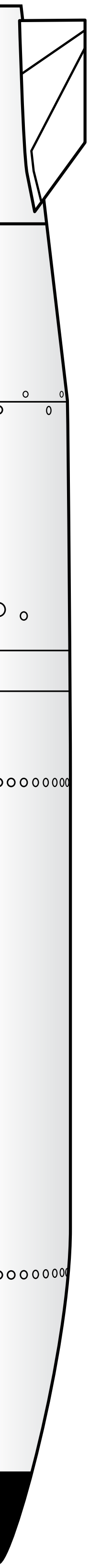
With sound waves, one or more acoustic generators would be set up against the head and aimed at the problem area inside the brain. This produces two significant difficulties, however. The first is getting the sound waves through the skull, although Sinha has already overcome that hurdle with a highly collimated ultrasound source that, unlike other sources, produces a beam whose shape does not depend on the sound-wave frequency. That allows him to project low-frequency waves capable of penetrating the skull along a narrow column across the brain.

Of course, that's not good enough; the sound must be restricted to a small target area in the brain and not an entire column through it. That's the second difficulty. But Sinha has that one covered too. With a technique called parametric mixing—Sinha has seven patents for this—two crossed beams deliver the desired acoustic signal to their intersection point only. In essence, this method of sound-wave targeting could allow different people to listen to different music in the same room, and in the brain, he believes it will produce reliably targeted stimulation (or disruption, as needed) for misfiring neurons. As an added bonus, he notes that the stimulation is highly adjustable in terms of sound modulation and energy delivery, allowing doctors to optimize the treatment settings for each patient.

Sinha is not yet experimenting with actual brains, so there is much research yet to be done. But if successful, his work could spawn a welcome shift in the treatment of serious mental disorders from expensive and dangerous surgeries to comparatively inexpensive and noninvasive sonic headgear.

—*Craig Tyler*

Digging Crystal Deep



As Los Alamos National Laboratory works to refurbish the B61 bomb—an aircraft-launched nuclear weapon it designed in the early 1960s—experimental scientists and weapons modelers are delving deep into the microstructure of TATB (triaminotrinitrobenzene), the high explosive that revolutionized the B61's safety. Unlike an earlier kind of explosive used in these weapons, TATB is extremely difficult to detonate by accident.

"You can set it on fire or slam it into a brick wall, and it won't blow up," says R&D engineer Bert Harry, who has seen conventional explosives triggered by a mere waist-height drop to the floor.

German-born Sven Vogel, a Los Alamos Neutron Science Center instrument scientist, says knowing TATB history adds meaning to his research for the B61, which is deployed in the U.S. and with North Atlantic Treaty Organization nations in Europe. In 1979, the B61 bomb switched from conventional explosives to TATB, making it the first nuclear weapon to enter the stockpile with an insensitive high explosive in the main charge. Earlier, in other bombs, some conventional high explosives had gone off haphazardly in the United States and abroad, taking lives, damaging homes, and contaminating land and water with radiation, according to declassified Department of Defense reports.

"Stories like that make clear why it is a good idea to have an insensitive high explosive," Vogel says, "and why one needs to understand how it behaves during the lifetime of a device in as much detail as possible."

TATB's discovery and rise to prominence followed three explosives accidents that killed a total of seven Los Alamos employees in the 1950s. The Laboratory pushed to create safer energetic materials, of which TATB was one, resulting in a fatality-free record since 1959. Los Alamos scientists patented the TATB manufacturing process and became the first national security lab to use an accident-resilient TATB composition in nuclear weapons.

The B61 bomb's plastic-bonded explosive, called PBX 9502, contains 95 percent TATB and was last produced commercially for the U.S. nuclear weapons stockpile in 1989. Now it's time to replenish the explosive as the U.S. Air Force and the National Nuclear Security Administration extend the lifespan of existing B61s for another 20 years. Although the explosives won't be made at Los Alamos, the Laboratory must assess the safety, reliability, and performance of any modified weapons that enter the stockpile without nuclear testing and is responsible for the quality of updated explosives.

Producing a perfect batch of PBX 9502 could be challenging, given new production methods and new environmental regulations that dictate a different way of making the plastic binder without the harsh chemicals of the past. That's where the science comes in. "We need to characterize the existing material extremely well so we can know for certain that the replacement material is as similar as possible," says Los Alamos explosives researcher John Yeager.

When the original batches of TATB were made, not only was the science of the explosive not fully understood but weapons modelers had no way to anticipate and prepare for environmental factors, such as temperature swings or natural disasters, during a weapon's decades of service. "The codes weren't sophisticated enough to handle details at the crystal level," explains Yeager, "so certain measurements were never made."

The codes caught up in the past decade, creating a need to measure TATB's fundamental properties and to study how expected and unexpected factors could alter those properties, perhaps rendering the explosive less powerful. Such data enable new computer simulations to make detailed predictions about how the explosive will behave and when it must be replaced.

"The shape of each crystal is flat like a card," Yeager says, "so packing the crystals into a three-dimensional charge is much like trying to build a house from cards." Moreover, TATB has a rare form of crystal asymmetry. When temperatures fluctuate, the crystal structure expands unevenly, irreversibly altering the shape and size of the bulk material.

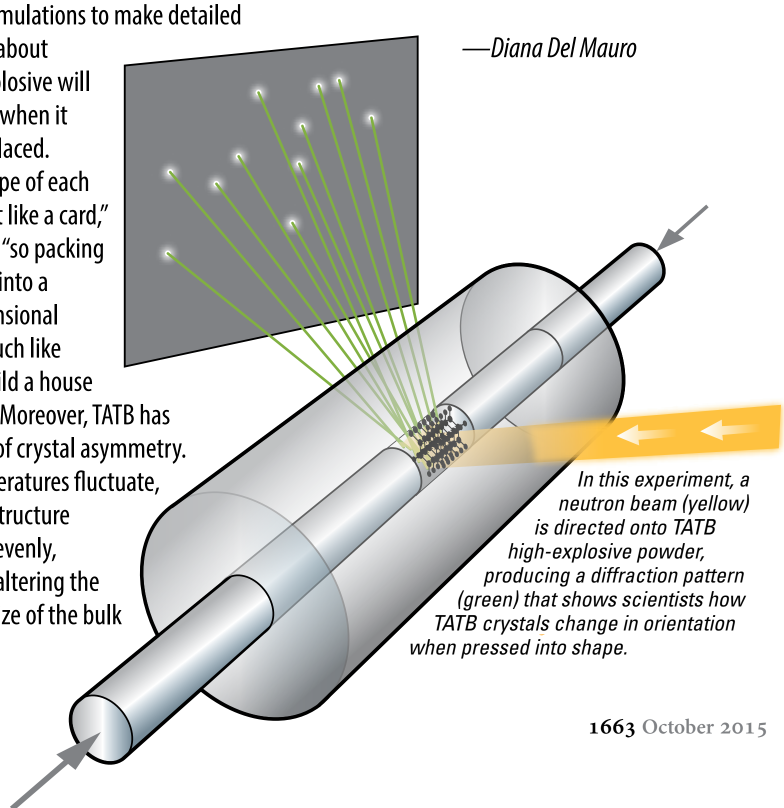
When B61 weapons modelers called on Yeager to observe and describe TATB's puzzling behavior during temperature changes, Yeager couldn't use the usual x-ray techniques, which might burn the sample when exposing crystal-level details at high resolution. With neutrons readily available at the Los Alamos Neutron Science Center, he looked to the facility's instrument scientists, including Vogel, to help him design a nondestructive approach.

Together, they collected neutron diffraction patterns from TATB powder as the explosive was subjected to cycling temperatures and compacting into charges. Their findings at the nanoscale (within the crystal) and microscale (hundreds of crystals) should clear up contradictory reports in the scientific literature and provide the "first-ever complete picture" of how the card-like crystals align during pressing, says Yeager. The data are already being fed into new computer simulations, which now account for changes in TATB properties that could occur while a weapon ages in a bunker or in off-normal scenarios, such as fire.

The research isn't just crucial for the B61. The latest federal guidance, according to a recent NNSA position paper, is that TATB—the only insensitive high explosive qualified for use in weapons by Department of Energy standards—should be adopted by all the nation's nuclear weapons.

A booming new era for TATB production could lie ahead.

—Diana Del Mauro



In this experiment, a neutron beam (yellow) is directed onto TATB high-explosive powder, producing a diffraction pattern (green) that shows scientists how TATB crystals change in orientation when pressed into shape.